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13. ABSTRACT (Maximum 200 words)

An important component of the work for AFOSR was the discovery and investigation of "riddled basins." A riddled basin for a chaotic attractor's basin is arbitrarily close to points in another attractor's basin (the first basin is "riddled" with holes). When an attractor has a riddled basin there is an extreme end-state sensitivity to initial conditions in the sense that for any initial condition in the riddled basin an arbitrarily small error in computation can result in the erroneous prediction of which attractor the initial condition is eventually attracted to. This contrasts with the more usual situation of a chaotic attractor with a non-riddled basin where any error in computation propagates exponentially but one can reliably say which attractor the initial condition is attracted to. Since the researchers discovery of the phenomenon of riddled basins, physical examples have been found in scattering, statistical mechanical, and ecological models. As can be seen from the bibliography, they have also done extensive work in other areas of dynamics, including the properties of indecomposable continua occurring in models of turbulent fluid flow. Dept of Mathematics Univ of Maryland College Park, MD 20742

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FINAL TECHNICAL REPORT
1 NOV 91 - 31 OCT 93

"THEORETICAL INVESTIGATIONS OF CHAOTIC DYNAMICS"

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F49620-92-J-0033

PREFACE

This end of contract Progress Report for the Air Force Office of Scientific Research (Research Grant AFOSR F49620-92-J-0033) entitled "Theoretical Investigations of Chaotic Dynamics" of the period November 1, 1991 to October 31, 1993 is organized under the following two parts:

PART I

1. Publications in reviewed journals (we are including papers accepted and submitted for publication).
2. Book(s) or book chapter(s) published:

   None
3. Graduate Students supported:

   None
4. Postdoctoral Associates supported:

   None
5. External honors including major prizes, society awards, fellows of major societies, invited plenary addresses at major conferences, etc.

PART II

1. Invention Report

PART III

1. Appended Preprints

PART I

1. Publications in reviewed journals (since this was a new grant, we are also including papers accepted and submitted for publication):

   a. "Riddled Basins", J. C. Alexander, I. Kan, J. A. Yorke, and Z. You, *Int. J. Bif. and Chaos* 2, 795-814 (1992).

   b. "Shadowing Orbits of Ordinary Differential Equations", B. A. Coomes, H. Koçak, and K. J. Palmer, submitted for publication.

   c. "Two Coexisting Structurally Stable Attractors, Each with an Everywhere Dense Basin", I. Kan, submitted for publication.

   d. "Evolution of Attractor Boundaries of Two-Dimensional Noninvertible Maps", W. Chin, I. Kan and C. Grebogi, *Random & Comp. Dyn.* 1, 349-370 (1993).

   e "How often are chaotic saddles nonhyperbolic?", Y-C. Lai, C. Grebogi, and J. A Yorke, Nonlinearity, 6, 779-797 (1993).

   f. "A Geometric Mechanism for Antimonotonicity in Scalar Maps with Two Critical Points", S. P. Dawson, C. Grebogi, H. Koçak, and J. A. Yorke, *Phy. Rev. E* 48, 1676 (1993).

   g. "Crisis in Chaotic Scattering", Y.-C. Lai, C. Grebogi, R. Blümel, and I. Kan, *Phys. Rev. Lett.* 71, 2212 (1993).

   h. "Maxwell on Chaos", B. R. Hunt and J. A. Yorke, *Nonlinear Science Today* 3, 1 (1993).

   i. "Periodic Shadowing", B. A. Coomes, H. Koçak, and K. J. Palmer, submitted for publication.

j. "The Forced Damped Pendulum and the Wada Property", J. Kennedy and J. A. Yorke", *Continuum Th. & Dyn. Syst.*, Lecture Notes in Pure & Applied Math. 149, 157-182 (1993).

k. "Pseudocircles in Dynamical Systems", J. Kennedy and J. A. Yorke, to appear *Trans. Amer. Math. Soc.*

l. "Bizarre Topology is Natural in Dynamical Systems", submitted to the *Bulletin of the American Math. Society.*

m. "Pseudocircles, Diffeomorphisms, and Perturbable Dynamical Systems", J. Kennedy and J. A. Yorke, submitted to *Ergodic Theory and Dynamical Systems.*

n. "The Topology of Attractors", J. A. Kennedy, submitted to *Ergodic Theory and Dynamical Systems.*

o. "Prevalence: a Translation-invariant "Almost Every" on Infinite Dimensional Spaces", B. Hunt, T. Sauer, and J. A. Yorke, *Bull. Amer. Math. Soc.* 27, 217-306 (1992).

p. "When Cantor Sets Intersect Thickly", B. R. Hunt, I. Kan, and J. A. Yorke, *Trans. Amer. Math. Soc.*, 339, 869-888 (1993).

2. External honors including major prizes, society awards, fellows of major societies, invited plenary addresses at major conferences, 3tc.:

a. Celso Grebogi, Fellow of the American Physical Society, elected November 1991.

b. Celso Grebogi's invited lectures at conferences:

1) "Shadowing of Chaotic Trajectories", Conference on Chaos in Dissipative Systems, Trassenheide, Germany, April 8-11, 1992 (One hour Lecture).

2) "History of Nonlinear Dynamics and Chaos", Workshop on the Head and Heart of Chaos: Nonlinear Dynamics in Biological Systems, National Institutes of Health, Bethesda, Maryland, June 15-16, 1992 (Opening Lecture).

3) "Control of Chaos", Conference on Nonlinear Dynamics in Optical Systems, Optical Society of America, Albach, Austria, June 22-26, 1992 (Forty-minute Lecture).

4) "Numerical Trajectories of Chaotic Systems", London Mathematical Society Symposium on Evolutionary Problems (Continuous and Discrete Problems). Grey College, Durham University, Manchester, England, July 4-14, 1992 (Keynote Lecture).

5) "Using Time Series for Feedback Control of Chaotic Systems", 1992 SIAM Annual Meeting, Los Angeles, California, July 20-24, 1992 (Half-hour Talk).

6) "Control of Chaos from Experimental Data", Workshop on Dynamical Measures of Complexity and Chaos, Bryn Mawr, Pennsylvania, August 13-15, 1992 (Forty-minute Lecture).

7) "Shadowing of Chaotic Systems", Third Colloquium on Differential Equations, Plovdiv, Bulgaria, August 18-22, 1992 (One-hour Lecture).

8) "Using Time Series for Feedback Control of Chaotic Systems", SIAM Conference on Control, Minneapolis, Minnesota, September 17-20, 1992 (Half-hour Lecture).

9) "The Measure of Nonhyperbolicity in Chaotic Dynamical Systems", SIAM Conference on Applications of Dynamical Systems, Salt Lake City, Utah, October 15-19, 1992 (Half-hour Lecture).

10) "Controlling Chaos", Dynamics Days Conference, Tempe, Arizona, January 6-9, 1993 (One-hour Lecture).

11) "Shadowing in Chaotic Systems", Pan-American Workshop for Applied and Computational Mathematics, Caracas, Venezuela, January 10-15, 1993 (One-hour Lecture).

12) "Numerical Trajectories of Chaotic Systems", Summer School of *Dynamical Systems and Nonlinear Analysis*, University of Cape Town, South Africa, January 24-February 5, 1993 (One-hour Lecture).

13) "Shadowing in Chaotic Systems", London Mathematical Society Meeting on Numerical Analysis and Dynamical Systems, University of Cambridge, England, May 13-14, 1993 (One-hour Lecture).

14) "Control and Targeting of Chaotic Systems", Int. Conference on Hamiltonian Mechanics: Integrability and Chaotic Behavior, Torun, Poland, June 1993 (One-hour Lecture).

15) "Controlling of Chaos from Experimental Data", SPIE's Annual Meeting, San Diego Convention Center, California, July 11-16, 1993 (One-hour Lecture).

16) "Controlling Chaos", IUTAM Sympotium on Nonlinearity and Chaos in Engineering Dynamics, University College, London, England, July 19-23, 1993 (One-hour Lecture).

17) "Shadowing in Chaotic Systems, Potsdam, Germany, August 30-September 3, 1993 (One-hour Lecture).

18) "Controlling Chaos", The Seventh Toyota Conference on Towards the Harnessing of Chaos, Lake Hamana Shizuoka, Japan, October 31-November 3, 1993 (One-hour Lecture).

c. James Yorke's invited lectures at conferences:

1) Oberwolfach, Germany, Conference on Applied Dynamics and Bifurcation, January 1992 (One-hour Lecture).

2) Naval Surface Warfare Center, Silver Spring, MD, Dynamics Day and a Half Minisymposium, 20 minute lecture, April 1992.

3) Carleton University, Ottawa, Canada, 14th Annual Analysis Day, April 1992 (One-hour Lecture).

4) Woudschoten, The Netherlands, Third International Symposium on Chaotic Dynamical Systems, Invited Speaker, 3 Lectures, June 1992.

5) Boston University, Regional Institute in Dynamical Systems, July 1992 (One-hour Lecture).

6) Orlando, Florida - World Congress of Nonlinear Analysts, 2 lectures August 1992.

7) Minneapolis, MN, SIAM Conference on Control and its Applications, half-hour lecture, September 1992.

8) Snowbird, UT, SIAM Conference on Applications of Dynamical Systems, 2 half-hour Lecture, October 1992.

9) Lexington, KY, Midwest Southeastern-Atlantic Second Joint Conference on Differential Equations, University of Kentucky, Keynote address, November 1992 (One-hour Lecture).

10) Tempe, AZ, Dynamics Days Arizona, Arizona State University, Lecture and short course, January 1993.

11) Albuquerque, NM, Sandia National Laboratory, 20 minute lecture, February 1993.

12) Waterloo, Canada, Workshop on Pattern formation and Symmetry Breaking in PDEs, February 1993 (One-hour Lecture).

13) Knoxville, TN, AMS Southeastern Meeting, March 1993 (One-hour Lecture).

14) University of South Carolina, Columbia, Spring Topology Conference, March 1993 (One-hour Lecture).

15) San Diego, CA, International Symposium SPIE, Keynote Speaker and Short Course (6 lectures), July 1993.

16) Budapest, Hungary, International Conf. on Complex Geometry in Nature, August 1993 (One-hour Lecture).

17) Como, Italy, NATO conference on Chaos "Order & Patterns: Aspects of Nonlinearity", September 1993 (One-hour Lecture).

18) Arlington, VA, 2nd Experimental Chaos conference, October 1993 (One-hour Lecture).

19) Penn State University, "Semi-annual Regional Workshop in Dynamical Systems", October 1993 (One-hour Lecture).

20) Washington, DC., Howard University, Dynamical Systems Week, October 1993 (One-hour Lecture).

21) Bethesda, MD (NIH), "Dynamical Systems Methods for the Study of Interactions of Genes and Environment", November 1993 (One-hour Lecture).

PART II

1. Invention Report

There are no inventions.

PART III

1. Appended Preprints